

Nitrogen recovery from urine in Space: a case for nitrification

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Abstract

Human life in space flights is currently enabled by a regular resupply of food and water. However, in order to explore deep space with long-term missions and space habitation, transport of food from earth becomes difficult and extremely expensive, if not impossible on the long run. In order to allow for deep space manned missions or permanent habitation, in situ food production in a regenerative life support system (RLSS) will most likely be necessary [1]. Nitrogen is a critical nutrient for such a cycle, and ~80% of the nitrogen in the food consumed is excreted and concentrated in the urine. This makes urine an attractive waste stream for nitrogen recovery and purification for subsequent proteinaceous food production. Although in some cases urea and ammonia can be taken up directly by plants and microorganisms grown for food production, it can be preferable to nitrify urea and ammonia, at least partially, to nitrate in a RLSS.

Nitrification of urine has been described for terrestrial applications, however typically synthetic and diluted urine was studied with bioreactors and microbial communities that are as such not compatible with specific requirements applicable for space (reduced gravity, pathogen-free synthetic microbial community, radiation levels). Through a series of studies, significant progress has been made towards application of urine nitrification in space.

First, the nitrification of real, undiluted urine could be established for the first time with a nitrification efficiency higher than 95% at a rate up to $0.4 \text{ g N L}^{-1} \text{ d}^{-1}$ combined with a COD removal efficiency of ~90-95%. After these lab-scale demonstrations, the nitrification of urine was also confirmed on breadboard level. Second, a selection of pure strains was performed to design a synthetic microbial community, capable of effectuating different microbial processes (ureolysis, ammonium and nitrite oxidation and COD oxidation) in a urine matrix. After confirmation with small scale batch tests, the process was demonstrated as well with real urine in a continuously fed bioreactor with membrane filtration. A third challenge is to address the reduced gravity, which hampers density driven convection, and the radiation imposed on the microorganisms to evolve to nitrification in space. Therefore, membrane aerated bioreactors have been developed for urine nitrification to provide the microorganisms with oxygen in an effective way in reduced gravity conditions. The survival and storage of the nitrifying strains during launch and space flight was verified in two experiments (NITRIMEL and BISTRO) demonstrating that nitrifying pure strains, synthetic co-cultures as well as mixed nitrifying microbial communities could successfully be reactivated after spaceflight in low earth orbit.

All these experiments have paved the way for future demonstrators of urine nitrification in space and should finally lead to a safe and effective reuse of nutrients from urine in outer space.

References

[1] Godia F, Albiol J, Montesinos JL, Perez J, Creus N, Cabello F, et al. MELISSA: a loop of interconnected bioreactors to develop life support in space. J Biotechnol. 2002;99:319-330.

